One-neutron transfer reactions in the neutron rich Ni-region

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& the MINIBALL Collaboration

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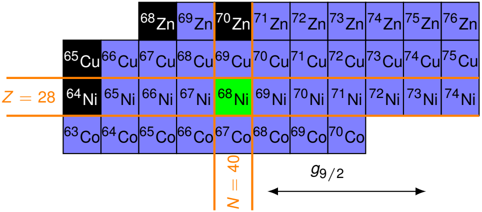
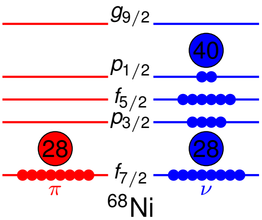
Outline

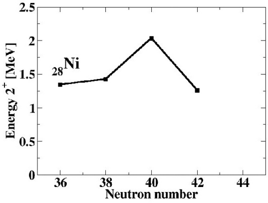
1. Introduction
   - The $Z = 28$, $N = 40$-region
   - $^{2}H(^{66}Ni,^{1}H)^{67}Ni$ One-neutron transfer reaction
2. Technique
   - Transfer reaction theory
   - Experimental Set-up
3. $^{2}H(^{86}Kr,^{1}H)^{87}Kr$ Test
4. Conclusion & Outlook

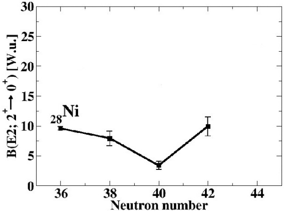
Outline

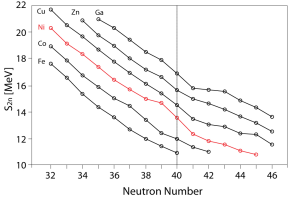
Overview


68Zn 69Zn 70Zn 71Zn 72Zn 73Zn 74Zn 75Zn 76Zn
65Cu 66Cu 67Cu 68Cu 69Cu 70Cu 71Cu 72Cu 73Cu 74Cu 75Cu
Z = 28
64Ni 65Ni 66Ni 67Ni 68Ni 69Ni 70Ni 71Ni 72Ni 73Ni 74Ni
63Co 64Co 65Co 66Co 67Co 68Co 69Co 70Co
N = 40
g9/2

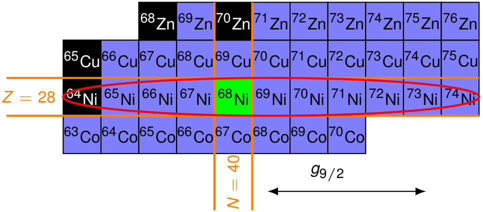

g9/2
40
p1/2
f5/2
p3/2
28
28
f7/2
π
ν
68Ni


Energy 2+ [MeV]
28Ni
Neutron number


B(E2; 2+ → 0+) [W.u.]
28Ni
Neutron number


S2n [MeV]
Cu
Zn
Ga
Ni
Co
Fe
Neutron Number

Overview



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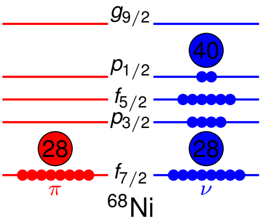

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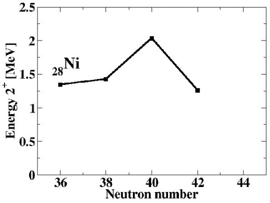

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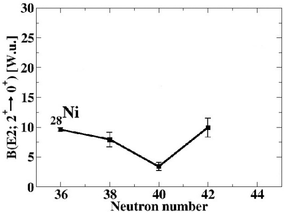

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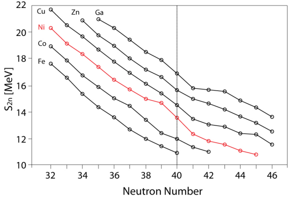

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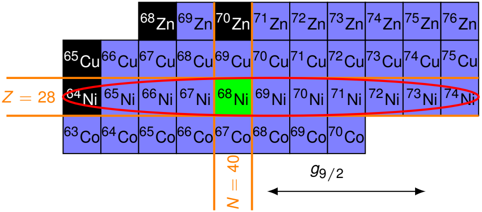
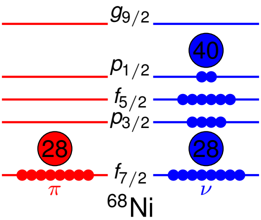
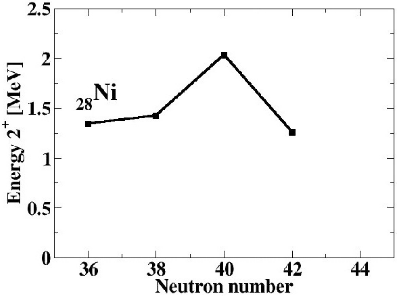
S2n [MeV]
Neutron Number

E_{2^+}, $B(E2, 2^+ \rightarrow 0^+)$ and S_{2n} Evolution

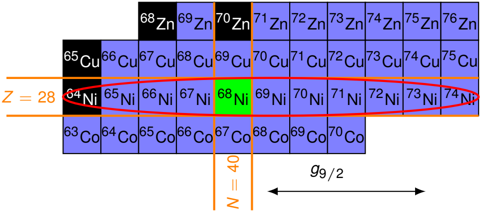


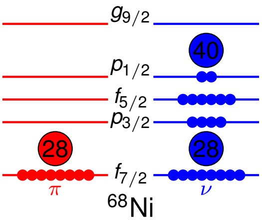


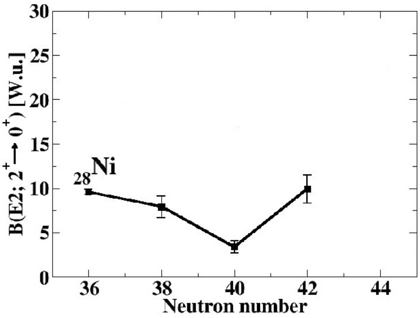


E_{2^+} peaks for $N = 40$
[Girod, 1988]

E_{2^+}, $B(E2, 2^+ \rightarrow 0^+)$ and S_{2n} Evolution

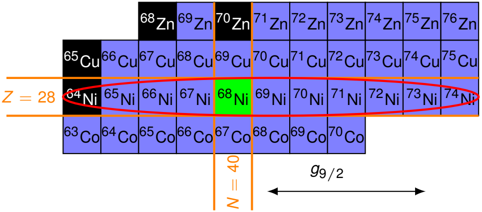


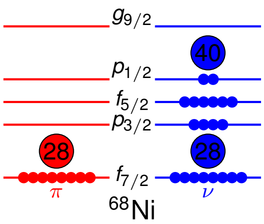


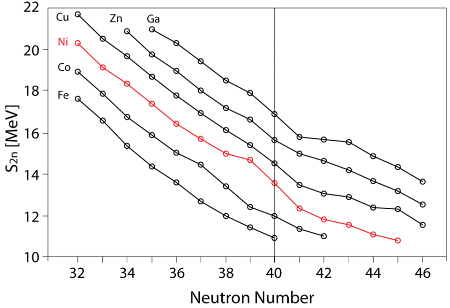


$B(E2, 2^+ \rightarrow 0^+)$ reaches minimum for $N = 40$ [Bree, 2008], [Sorlin, 2002]

E_{2^+}, $B(E2, 2^+ \rightarrow 0^+)$ and S_{2n} Evolution

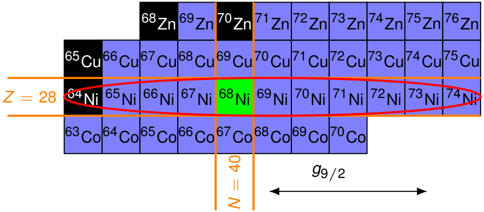


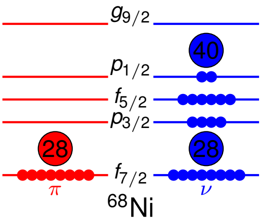




S_{2n} shows no irregularity [Rahaman, 2007]

Objectives





- Controversial conclusions about the nature of the $N = 40$-Harmonic oscillator subshell closure [Sorlin, 2008]
- Study single-particle character of the excited states in the neutron rich Ni isotopes using transfer reactions
- ^{67}Ni as starting point (^{68}Ni $\otimes \nu^{-1}$)

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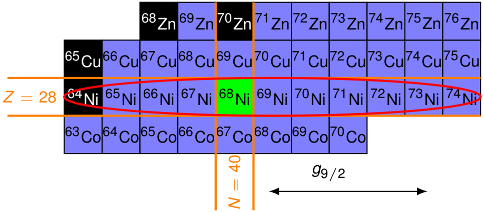

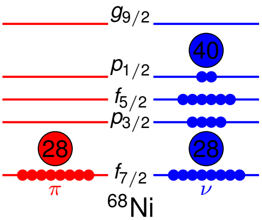

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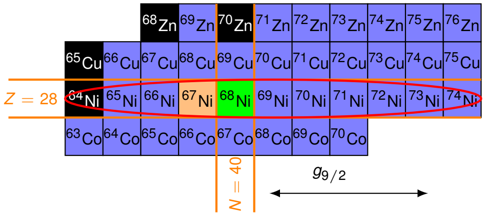

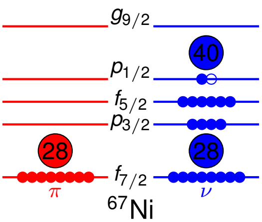

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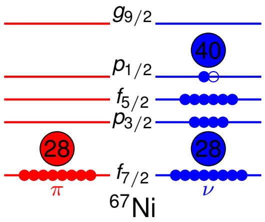
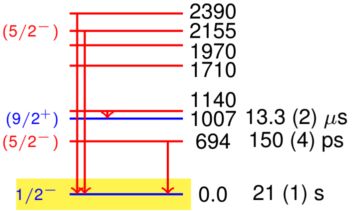
$^{2}H(^{66}Ni, ^{1}H)^{67}Ni$

Questions

- Study the ground state structure ($^{68}Ni \otimes \nu^{-1}$)
- g-factor of the $9/2^{+}$-state is smaller by a factor of 2 than expected for a $1g_{9/2}$-state [Georgiev, 2002]
- Determination of spin and parity of the first excited states
- Investigation of the single particle character of these levels → *Spectroscopic factors*

[Oros-Peusquens & Mantica, 2000]





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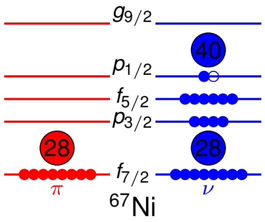

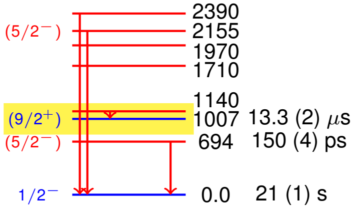

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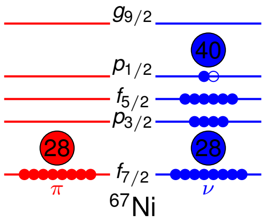

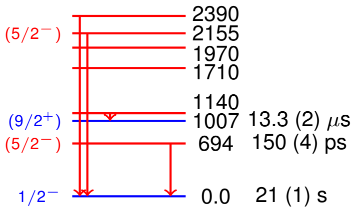

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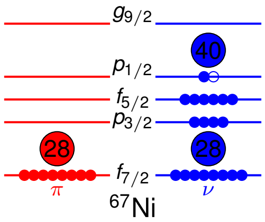

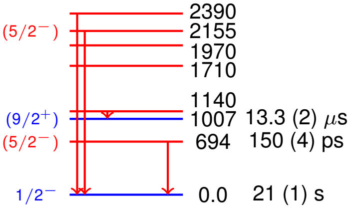

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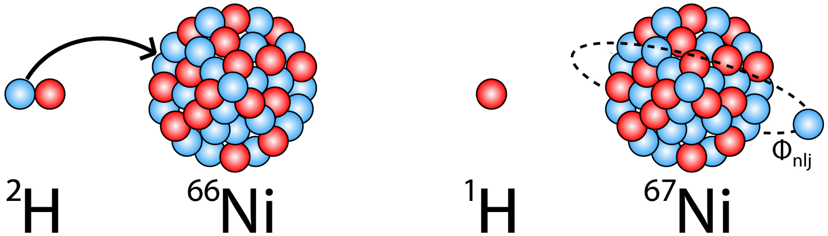
DWBA Theory

- $\frac{d\sigma}{d\Omega}$ describes $a + A \rightarrow b + B$ $(\alpha \rightarrow \beta)$
- $\frac{d\sigma}{d\Omega}$ depends on $\langle \Psi_\beta(\vec{k}_\beta)|H|\Psi_\alpha(\vec{k}_\alpha)\rangle$, with $H = V_a + V_A - \frac{\hbar^2}{2\mu_\alpha}\nabla^2_\alpha + V_\alpha$
- Use model for interaction potential [Glendenning, 2004]
- Tread transfer as perturbation on the elastic scattering
- $M_{\beta\alpha} = \int \chi_\beta^{(-)*}(\vec{k}_\beta, \vec{r})\langle\psi_B \mid \psi_A\rangle\langle\psi_b \mid V_{bx} \mid \psi_a\rangle\, \chi_\alpha^{(+)}(\vec{k}_\alpha, \vec{r})d\vec{r}$
- Assume extra neutron in B goes to a pure shell model orbital ($B = A \otimes \phi_{nlj}$)



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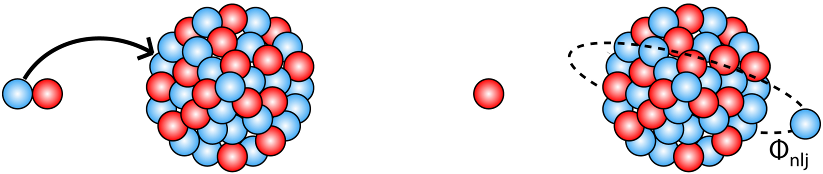

^{2}H ^{66}Ni ^{1}H ^{67}Ni

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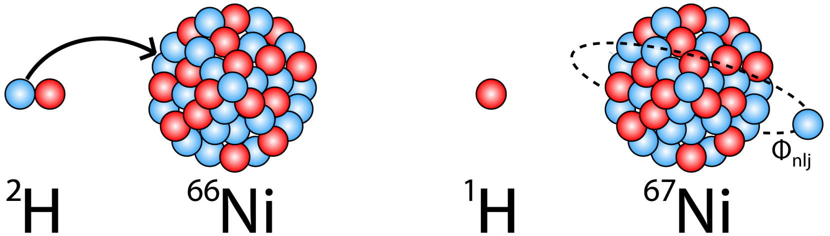

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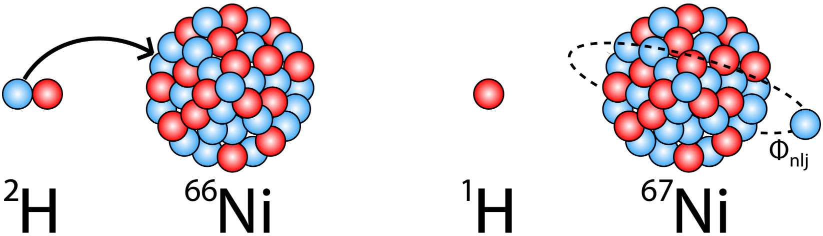

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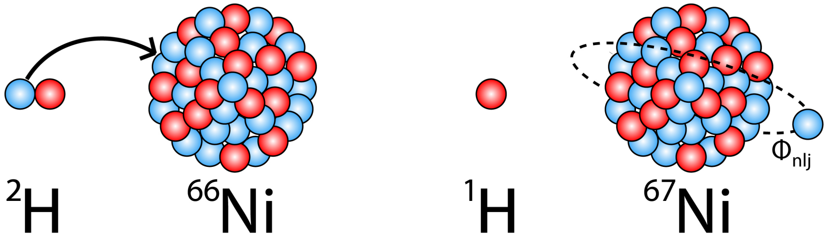

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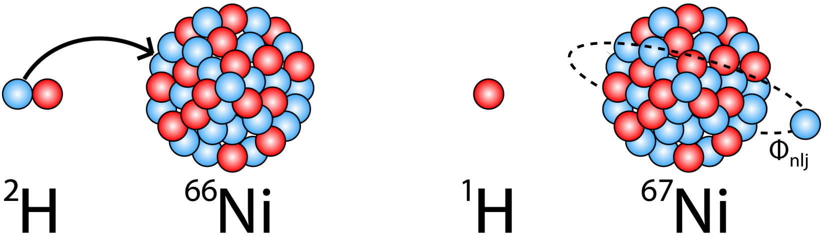

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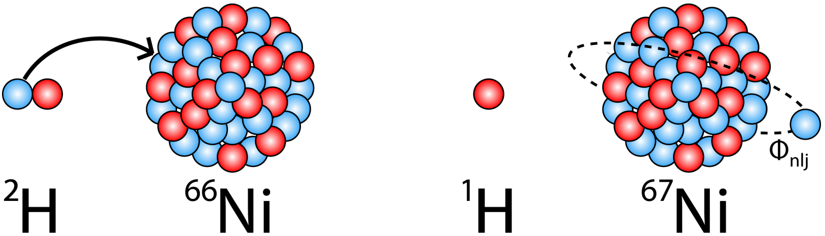

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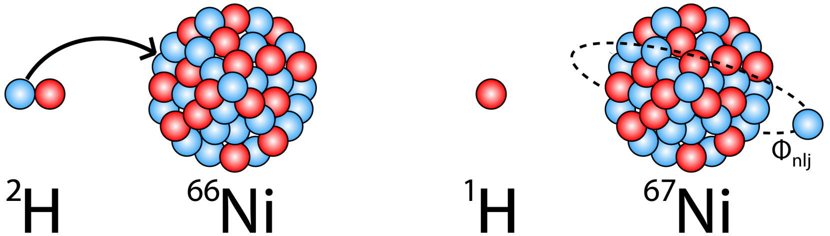

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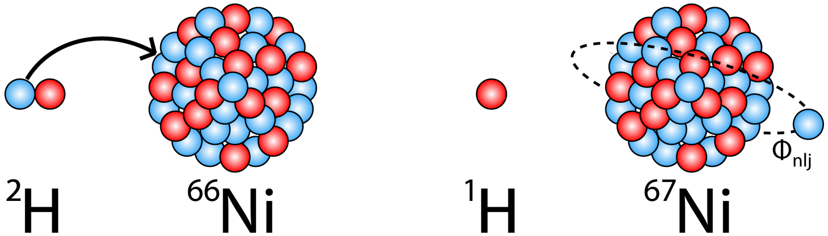
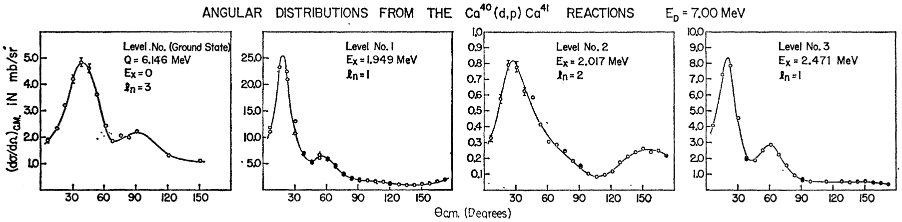
- Use model for interaction potential [Glendenning, 2004]
- Tread transfer as perturbation on the elastic scattering
- $M_{\beta\alpha} = \int \chi_\beta^{(-)*}(\vec{k}_\beta, \vec{r})\langle\psi_B \,|\, \psi_A\rangle\langle\psi_b\,|V_{bx}|\,\psi_a\rangle\, \chi_\alpha^{(+)}(\vec{k}_\alpha, \vec{r})d\vec{r}$
- Assume extra neutron in B goes to a pure shell model orbital ($B = A \otimes \phi_{nlj}$)



Example: $^{40}Ca(^{2}H,^{1}H)^{41}Ca$



[Belote, 1965]

- Shape of angular distribution gives info on angular momentum transfer (l) and parity.
- Scaling of the theoretical cross section to the experimental yields information on purity of the state. $\frac{d\sigma_{exp}}{d\Omega} = S\frac{d\sigma_{th}}{d\Omega}$
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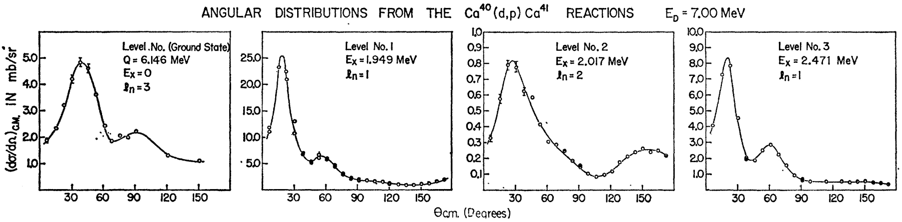

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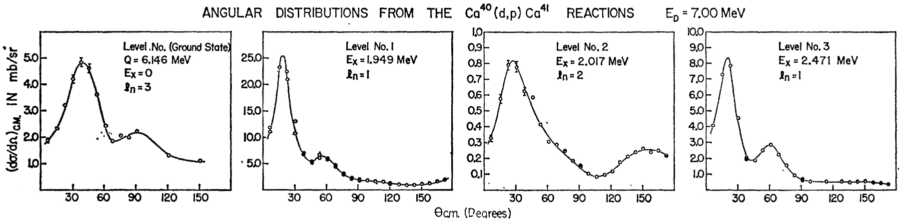

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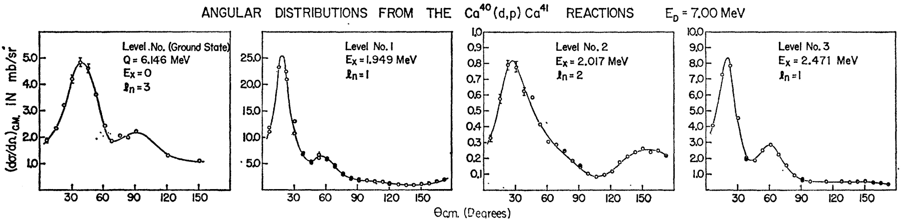

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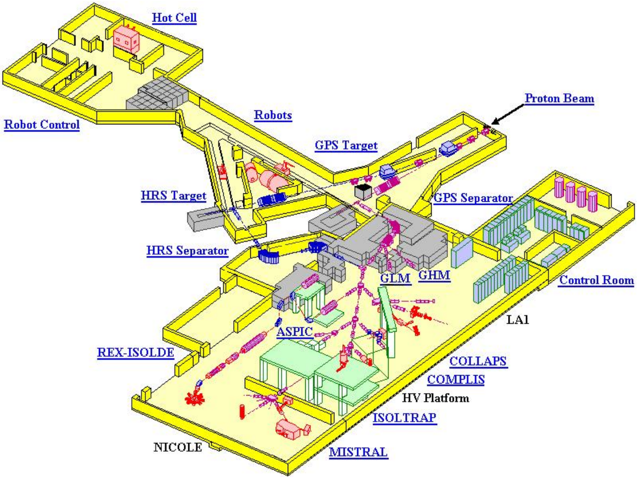
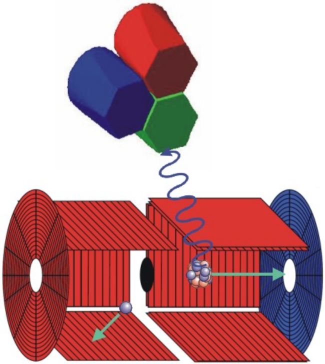
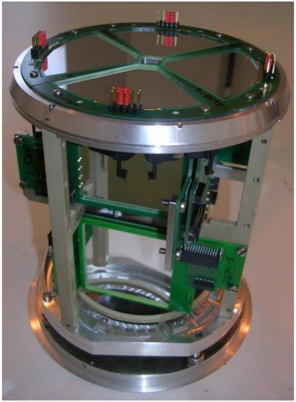
REX-ISOLDE



1. 1.4 GeV Proton beam ($2\mu A$) on UC_x-target
2. Laser ionisation by RILIS (Z-selection)
3. Isotope selection by GPS
4. Bunching and charge breeding in REX-TRAP and EBIS
5. Post-acceleration by REX (3 MeV/u)
6. Arrival at MINIBALL Set-up

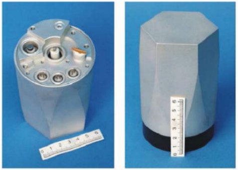
T-REX @ MINIBALL I

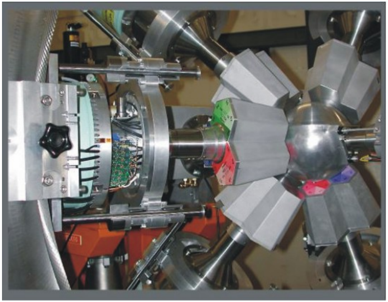


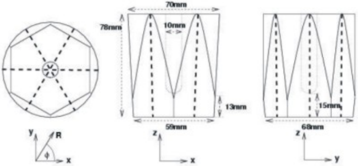


Detector	Angles	Thickness	Segmentation
Forw. CD (ΔE)	8-30	300 μm	16 annular x 24 radial
Forw. CD (E)	8-30	1.5 mm	-
Forw. Barrel (ΔE)	30-75	140 μm	16 resistive strips
Forw. Barrel (E)	30-75	1000 μm	-
Back. Barrel (ΔE)	104-152	140 μm	16 resistive strips
Back. Barrel (E)	104-152	1000 μm	-
Back. CD	152-172	500 μm	16 annular x 24 radial

MINIBALL γ-array







Main characteristics

- 8 Miniball clusters
- Each cluster: 3 HPGe crystals
- Each crystal: 6-fold segmented
- 6% efficiency @ 1 MeV

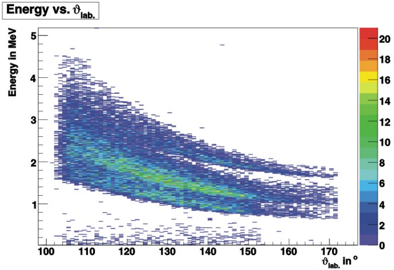
T-REX @ MINIBALL II

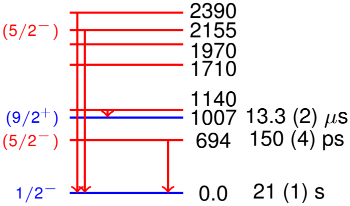
"Thick" ($1 mg/cm^2$) target measurement

- Spectroscopic information up to 3.0 MeV
- Coincidences with γ rays

"Thin" ($100 \mu g/cm^2$) target measurement

- *Spectroscopic information for the ground and the $1g_{9/2}$ state*
- Proton spectrum in singles
- Good energy resolution required
- Backward angles only

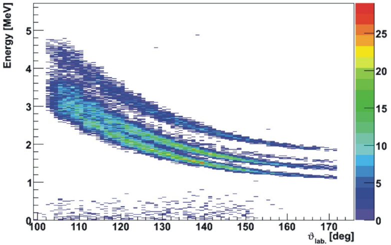




T-REX @ MINIBALL II

"Thick" (1mg/cm^2) target measurement

- Spectroscopic information up to 3.0 MeV
- Coincidences with γ rays



"Thin" (100μg/cm^2) target measurement

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- Good energy resolution required
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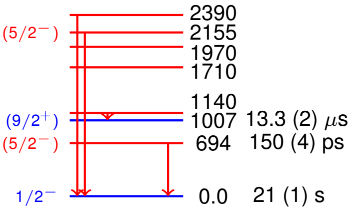
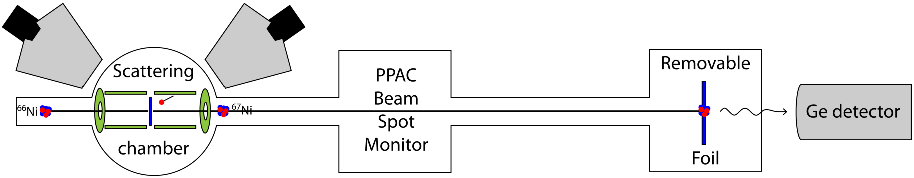


Slow Correlation Technique



Under investigation by Iain Darby.

Idea

Collection of isotopes on a foil surrounded with γ-detectors and make a slow correlation with protons detected in the scattering chamber.

Potential issues

- Build-up of activity → removable foils (radiation safety)
- Implementation into analysis code

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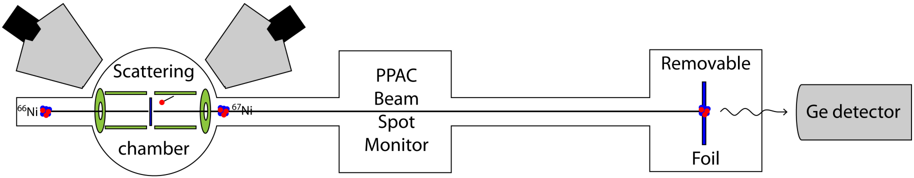

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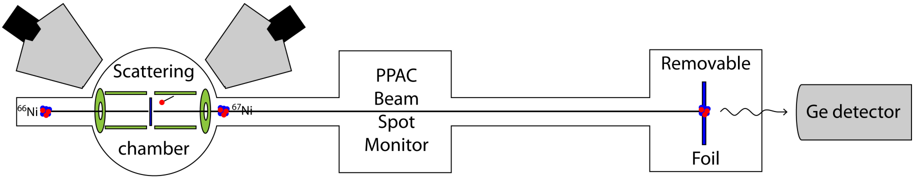

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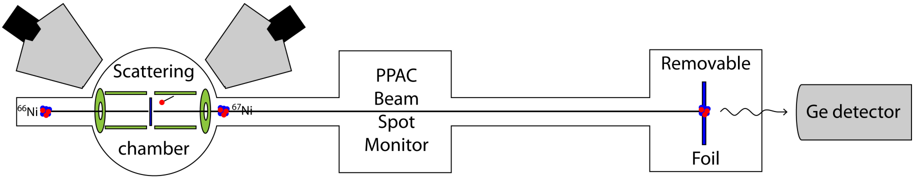

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- Test-run with 2.88 MeV/u stable ^{86}Kr-beam on CD_2 target was performed
- Goal 1: Test of the set-up with heavier beams.
- Goal 2: Reproduction of ^{86}Kr(d,p)^{87}Kr data in direct kinematics [Haravu, 1970].
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Thick target measurement

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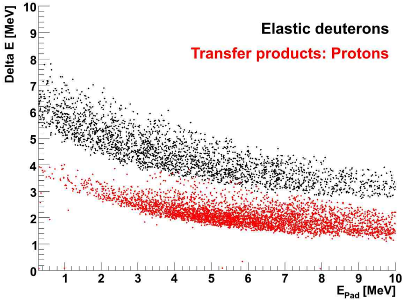

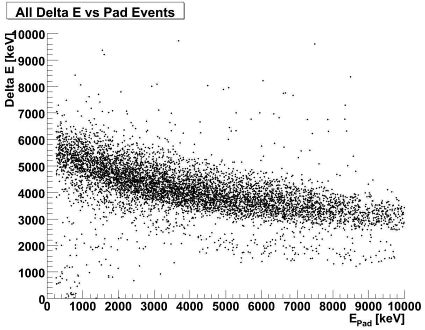

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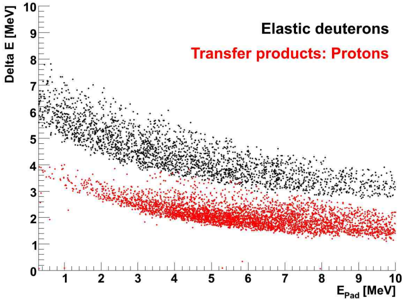
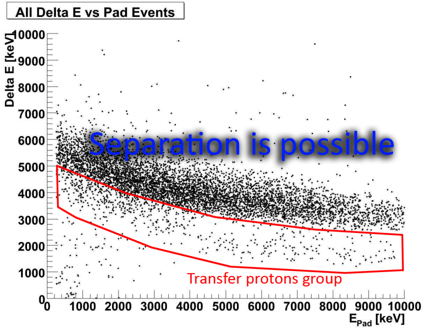
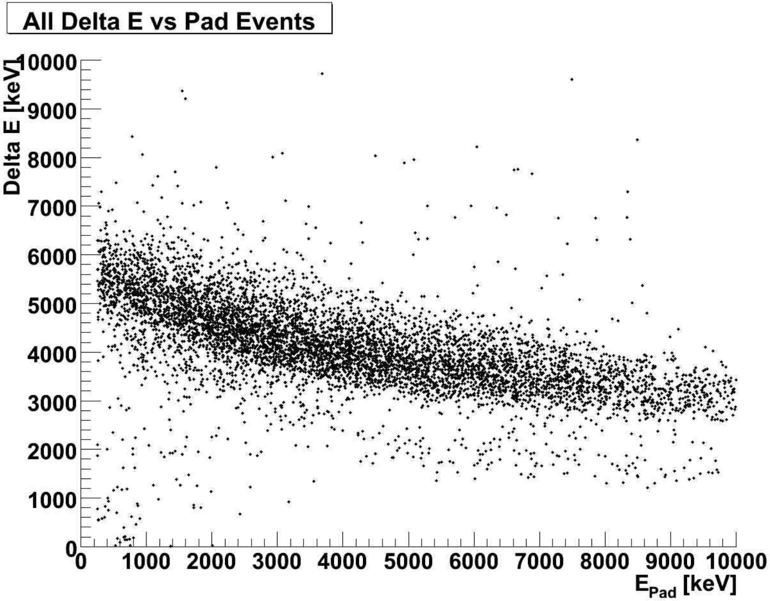




Experimental ΔE vs E



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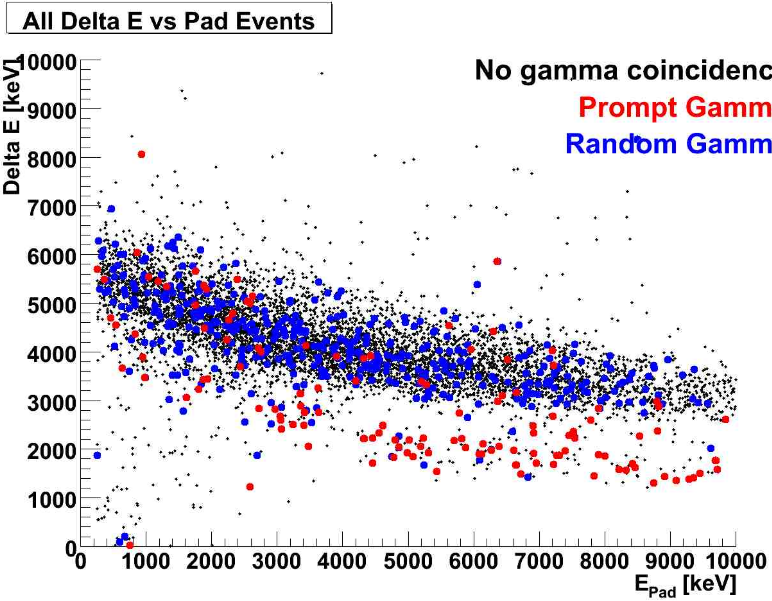

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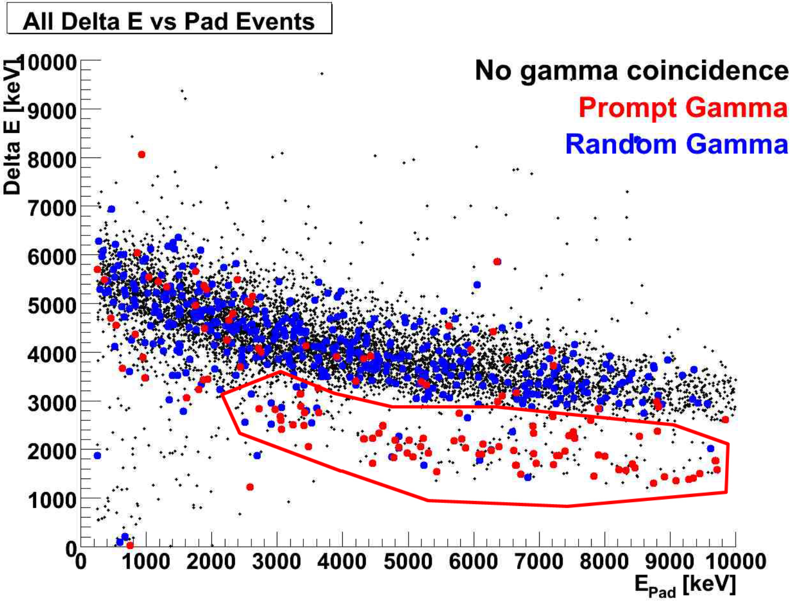

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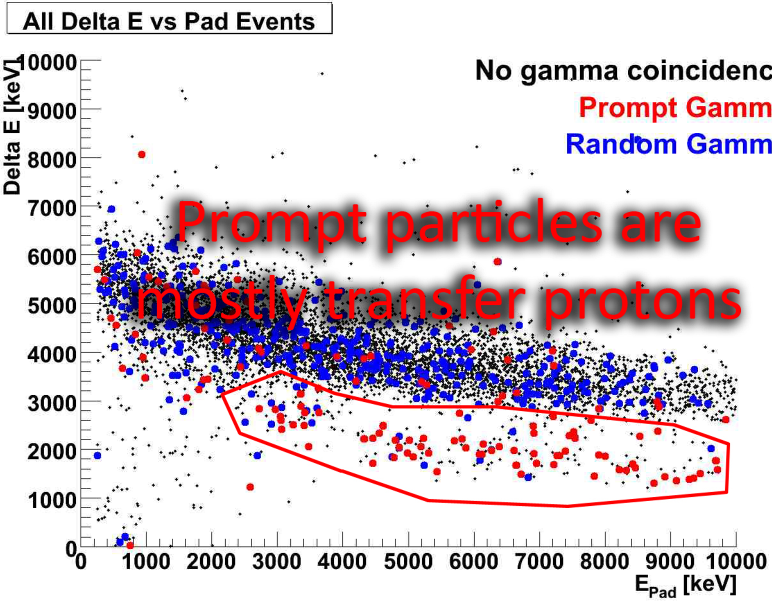
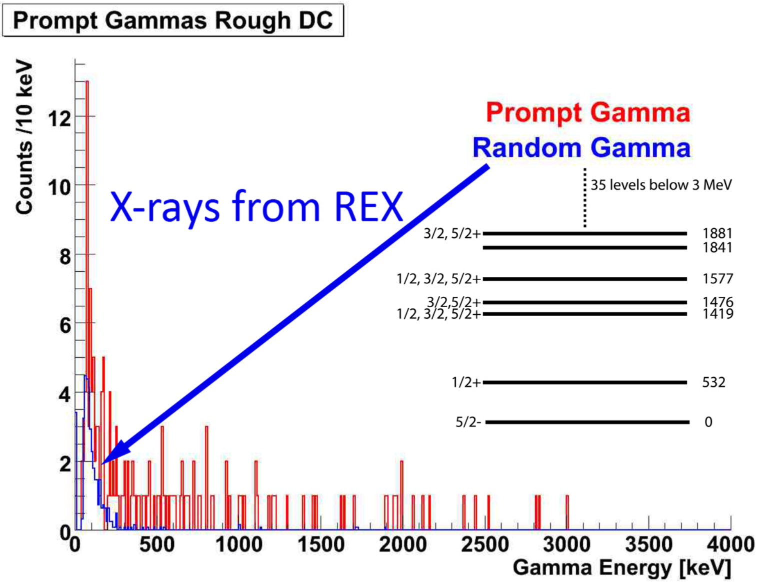
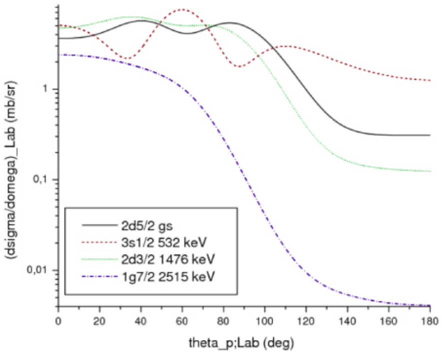
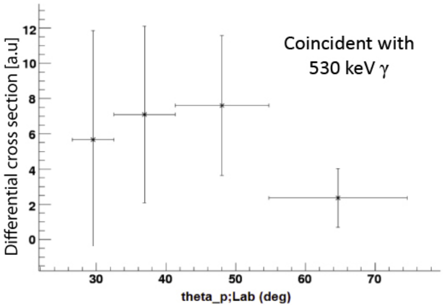


γ-spectra



Comparison with DWBA calculations





Inconclusive due to limited statistics [Vermaelen, 2009]

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  - Approved and scheduled $^{2}H(^{66}Ni,^{1}H)^{67}Ni$ experiment @ REX-ISOLDE (november 2009)
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For Further Reading I

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For Further Reading II

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- P. Vermaelen
  Master thesis KU Leuven, 2009

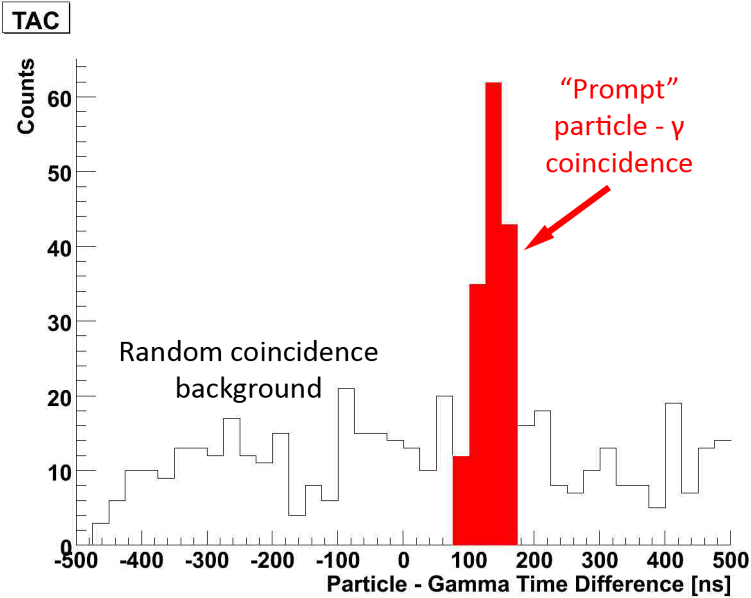
For Further Reading III

N. Patronis *et al.*
Proposal to the INTC Committee

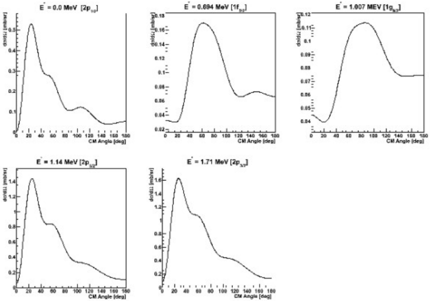
The Collaboration

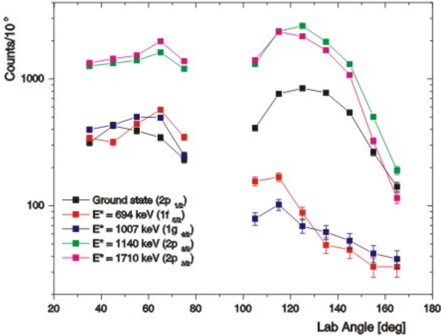
KU Leuven, TU München, University of Liverpool, Lund University, University of Edinburgh, University of Manchester, CSNSM Orsay, CERN, University of Paisley, IPN Orsay, LMU München, University of York, Universität zu Köln, INP Democritos, TU Darmstadt

Particle - γ time difference



^{66}Ni(d,p) DWBA Calculations





Calculations performed by N. Patronis [INTC, 2008]